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RESEARCH MEMORANDUM

THE TRANSONIC AERODYNAMIC CHARACTERISTICS OF STRUCTURALLY RELATED WINGS OF LOW ASPECT RATIO HAVING A SPANWISE VARIATION IN THICKNESS RATIO - TRANSONIC BUMP TECHNIQUE

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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SUMMARY

Wings having aspect ratios of 4, 3, and 2 with a plan-form taper ratio of 0.5 and a thickness taper ratio of 0.33 were investigated to determine their transonic longitudinal characteristics and the effects of tapering thickness ratio. These wings were structurally related by an increase in thickness ratio proportional to the aspect ratio on the basis of simple loading considerations. The tests were made for a Mach number range from 0.60 to 1.10 using the wind-tunnel-bump testing technique.

The results show that for the selected criterion of equal bending stress, the resultant combined effects of reducing aspect ratio and thickness ratio produced large reductions in minimum drag and gave greater maximum lift-drag ratios at low supersonic Mach numbers. As would be expected, decreasing the aspect ratio reduced the lift-curve slope throughout the Mach number range, overshadowing the effect of reduced thickness ratio. Good agreement was indicated for the lift-curve slope and the drag characteristics between the wings tapered in thickness ratio and the wings of equivalent uniform thickness ratio.

INTRODUCTION

Tapering the thickness ratio of a wing may permit savings in structural weight by providing a more efficient distribution of stress. In addition, for the same root-bending stress, tapering thickness ratio will improve the transonic aerodynamic characteristics by decreasing the effective thickness of the wing.

An experimental research program has been conducted at the Ames 16-foot high-speed wind tunnel to investigate the transonic longitudinal

characteristics of a large number of wings of related plan form and section using the bump testing technique. Some of the results have been published in references 1 to 5 to show the effects of systematic variations of aspect ratio, camber, thickness, and plan-form and thickness taper ratios. As part of this research program, tests were made to show the relation of the aerodynamic parameters of wings having aspect ratios of 4, 3, and 2 and having thickness ratios tapered in accordance with a simple structural criterion. The structural criterion relating the three wings was based on maintaining the same bending stress in all wings for a given percent span and lift coefficient while keeping the plan-form taper ratio and thickness taper ratio constant. The wings were assumed solid and the loading on each section was assumed proportional to the chord. As a consequence of these assumptions, the thickness ratios of the wings were directly proportional to their aspect ratio, and the stress was independent of the size or scale of the wings. Thus, direct comparisons can be made on the basis of equal load-carrying capacity if the small differences in Reynolds number between the wings can be ignored.

NOTATION

C_D drag coefficient, $\dfrac{\text{twice semispan drag}}{qS}$

C_L lift coefficient, $\dfrac{\text{twice semispan lift}}{qS}$

$C_{L_{max}}$ maximum lift coefficient

C_m pitching-moment coefficient, referred to $0.25\bar{c}$,

$$\frac{\text{twice semispan pitching moment}}{qS\bar{c}}$$

A aspect ratio, $\dfrac{b^2}{S}$

$\left(\dfrac{L}{D}\right)_{max}$ maximum lift-drag ratio

M Mach number

M_L local Mach number

S total wing area (twice wing area of semispan model), sq ft

V	velocity, ft/sec
b	twice span of semispan model, ft
c	local wing chord, ft
$\bar{c}$	mean aerodynamic chord, $\frac{2}{S}\int_0^{b/2} c^2 dy$, ft
q	dynamic pressure, $\frac{1}{2}\rho V^2$, lb/sq ft
$\frac{t}{c}$	thickness-to-chord ratio
y	spanwise distance from plane of symmetry, ft
α	angle of attack, deg
λ	plan-form taper ratio
ρ	air density, slugs/cu ft

MODELS AND APPARATUS

Models

The plan forms of the wings and the pertinent dimensional data defining the geometry of the wings are shown in figure 1. As can be seen from this figure, the plan forms of the three wings had the same root and tip chords (taper ratio of 0.5) and zero sweep of the 0.5c line. Symmetrical 63A-series sections and a thickness-ratio taper of 0.33 were used for all wings. Straight lines were used to join the root and the tip giving the thickness-ratio variations shown in figure 2.

Apparatus

The wings were mounted on the transonic bump in the Ames 16-foot high-speed wind tunnel as shown in figure 3. A detailed description of the bump is given in reference 6. Aerodynamic forces and moments were measured by a strain-gage balance mounted inside the bump. A fence was attached to the wings near the bump surface to restrict the flow of air through the gap in the surface (see figs. 1 and 3).

TESTS AND PROCEDURE

Range of Test Variables

The investigation was made for a range of Mach numbers from 0.60 to 1.10 with a corresponding Reynolds number range from about 1.5×10^6 to 1.8×10^6. Lift, drag, and pitching moment of the wings were measured as the angle of attack varied from about -2° to 24°. This range of angles of attack was reduced at higher Mach numbers because of limitations of wing strength or equipment.

Reduction of Data

Tare corrections have been applied to the drag to account for the effects of the wing fence. These tares were ascertained by cutting a wing flush with the fence and measuring the drag of the remaining fence and support combination. No attempt was made to correct the data for the effects of fence interference or leakage since no adequate method of evaluation was known.

The test Mach numbers represent mean values of the local Mach numbers that were measured over the bump in the region occupied by the wings. Typical local Mach number contours are illustrated in figure 4 to indicate the gradients that existed over the wings. Although the local Mach number gradients increased with increasing Mach number, the effects of these gradients on the results of the tests are believed to be small and probably confined largely to a rounding off of the force breaks. The comparison of bump and center-of-tunnel data for other wings made in reference 7 is believed typical of the agreement that could be expected for the wings reported herein.

RESULTS AND DISCUSSION

Combined Effects of Aspect Ratio and Thickness Ratio

The lift, pitching-moment, and drag characteristics of the structurally related wings are presented in figures 5, 6, and 7 for wings having aspect ratios of 4, 3, and 2, respectively. As previously discussed in the introduction, the structural criterion relating the three wings was based on maintaining the same bending stress in the wings for a given percent span and lift coefficient. One of the results of the assumption of this criterion was that the thickness ratios of the wings were directly proportional to their aspect ratios. To illustrate more clearly the combined effects of reducing aspect ratio

and therefore thickness ratio, a direct comparison of the data for the three wings is made in figure 8 for Mach numbers of 0.70 and 1.06. The comparison made in figure 8 shows that reducing the aspect ratio and the thickness ratio decreased the lift-curve slope and increased the drag due to lift for both Mach numbers. These effects are attributed primarily to decreasing the aspect ratio, since the results of reference 3 indicate that decreasing the thickness ratio had the opposite effect on the lift-curve slope and the differences in drag due to loss of leading-edge suction would probably be small for wings having the thicknesses used in these tests, particularly at a Mach number of 1.06.

The most significant advantage observed for the wing having an aspect ratio of 2 was a large reduction of minimum drag at supercritical Mach numbers, as illustrated in figure 8(b) for a Mach number of 1.06. This reduction in minimum drag was sufficient to offset the greater drag due to increasing lift coefficient, thus giving generally higher maximum lift-drag ratios for Mach numbers greater than about 1.00. The pitching-moment characteristics were generally similar for all three wings at a Mach number of 0.70 but, as Mach number increased to 1.06, the wing having an aspect ratio of 2 had lower stability for lift coefficients less than about 0.3. (See fig. 8(b).) Above 0.3 lift coefficient the stability was about the same for all wings. It should be noted that on the basis of equal wing areas, the absolute travel of the aerodynamic center for Mach numbers from 0.70 to 1.06 might be greater for the wing of aspect ratio 2 than for the wing of aspect ratio 4 since the wing of aspect ratio 2 would have about 41-percent-longer mean aerodynamic chord. Thus, for a lift coefficient of 0.3, the wing of aspect ratio 2 had about 3-percent-greater absolute travel of the aerodynamic center than the wing of aspect ratio 4; however, for a lift coefficient of 0, its travel was only about 20 percent as great.

Effects of Tapered Thickness Ratio

The effects of spanwise variation in thickness ratio are indicated by a comparison of the results for the wings reported herein with those having identical plan form but constant thickness ratios. Such a comparison is shown in figures 9 to 13 wherein the pertinent aerodynamic parameters for the wings of tapered thickness ratio of this investigation and the wings of constant thickness ratio of reference 3 are presented as functions of Mach number. Also shown are the parameters for wings of constant percent thickness having the same effective thickness ratio as the wings of tapered thickness ratio. These parameters were obtained by fairing the results taken from reference 3. The effective thickness ratio represents a weighted value, as discussed in reference 4, and is defined by the relationship

$$\left(\frac{t}{c}\right)_{effective} = \left[\frac{2}{S}\int_0^{b/2}\left(\frac{t}{c}\right)^{5/3} c\,dy\right]^{3/5}$$

The basis for this relationship stems from the transonic similarity rules for the rise of the minimum pressure drag at a Mach number of 1.0. (See ref. 2.) The effective thickness ratios of the wings of aspect ratios 4 and 2 were 0.047 and 0.024, respectively. No comparisons were made for the wing of aspect ratio 3 since comparative data were unavailable. It should be noted that since the mean effective thickness is based on drag considerations, any agreement of the aerodynamic parameters other than drag might be fortuitous.

The variation of lift-curve slope at zero lift with Mach number presented in figure 9 shows that for the wings having an aspect ratio of 4 (for which variations in thickness ratio had a significant effect on lift-curve slope), the lift-curve slope of the wing of tapered thickness ratio was in reasonable agreement with that of the wing having the same effective thickness ratio of 0.047. Closer agreement was indicated for the wings of aspect ratio 2 but this would be expected for such low aspect ratio and for the thin wings being considered.

Generally higher maximum lift coefficients are indicated in figure 10 for the wings with tapered thickness ratio as compared with wings having the same effective thickness ratio. It can be observed that decreasing thickness ratio increased the maximum lift coefficient somewhat. (See fig. 10.) It appears that this is the reason that the wings of tapered thickness ratio had greater maximum lift coefficients than wings whose thickness ratio equaled the root thickness ratio of the wings of tapered thickness ratio. It should be noted that the Reynolds numbers of the tests were low and also that the results might be sensitive to model surface condition. The dependence of maximum lift on Reynolds number probably limits the usefulness of the maximum lift results to Reynolds numbers approximated by those of the test.

The slopes presented in figure 11 of the pitching-moment curves for zero lift indicate that at subcritical Mach numbers for wings of aspect ratio 4, the aerodynamic center moved toward the leading edge with increasing thickness ratio. Since, at Mach numbers greater than 1.00, the aerodynamic-center position appeared practically independent of thickness ratio and was at about $0.40\bar{c}$ for all thicknesses, the over-all movement of the aerodynamic center for the Mach number range of the investigation increased somewhat with increasing thickness ratio. The position and the transonic changes of the aerodynamic center for the wing of tapered thickness ratio were intermediate between those for wings having constant thickness ratio encompassing the thicknesses of the wing of tapered thickness ratio, 0.060c to 0.020c. Although the pitching-moment-curve slopes for the wing having tapered thickness ratio and an aspect ratio of 4 were reasonably approximated by a wing having

the same effective thickness, 0.047c, a wing of the same average thickness, 0.040c, appeared to give closer agreement. For the wing having an aspect ratio of 2, the over-all effects of thickness ratio and its taper on the movement of the aerodynamic center appeared small for the thicknesses considered, except for Mach numbers slightly less than 1.0.

A reasonably close approximation to the minimum drag of the wings having tapered thickness ratio is indicated in figure 12(a) by wings having the same effective thickness. Except at the lower subsonic Mach numbers for the wing of aspect ratio 4, similar close agreement of the drag is shown in figure 12(b) for a lift coefficient of 0.4. It is evident that at least for the wing having an aspect ratio of 4, the selection of a wing having the same average thickness, 0.040c, for comparison would give poor agreement at supercritical Mach numbers. This is some justification for the procedure used to evaluate the effective thickness. The good agreement of the drag characteristics of wings having tapered thickness ratio with wings of the same effective thickness was reflected by similar agreement of the maximum lift-drag ratios shown in figure 13.

CONCLUDING REMARKS

The results of a transonic wind-tunnel investigation of wings having aspect ratios of 4, 3, and 2 and correspondingly reduced thickness ratio to provide equal bending stress show that the resultant combined effects of reducing aspect ratio and thickness ratio produced large reductions in minimum drag at transonic speeds. This reduction of minimum drag was sufficient to offset the greater drag due to lift and led to generally higher maximum lift-drag ratios for Mach numbers greater than about 1.00. As might be expected, decreasing the aspect ratio reduced the lift-curve slope and overshadowed any effects of reduced effective thickness ratio. Good agreement was indicated for the lift-curve slope and the drag characteristics between the wings tapered in thickness ratio and the wings of equivalent uniform thickness ratio.

Ames Aeronautical Laboratory
National Advisory Committee for Aeronautics
Moffett Field, Calif., Feb. 18, 1954

REFERENCES

1. Nelson, Warren H., and McDevitt, John B.: The Transonic Characteristics of 17 Rectangular, Symmetrical Wing Models of Varying Aspect Ratio and Thickness. NACA RM A51A12, 1951.

2. McDevitt, John B.: A Correlation by Means of the Transonic Similarity Rules of the Experimentally Determined Characteristics of 22 Rectangular Wings of Symmetrical Profile. NACA RM A51L17b, 1952.

3. Nelson, Warren H., Allen, Edwin C., and Krumm, Walter J.: The Transonic Characteristics of 36 Symmetrical Wings of Varying Taper, Aspect Ratio, and Thickness as Determined by the Transonic-Bump Technique. NACA RM A53I29.

4. Nelson, Warren H.: The Transonic Characteristics of Unswept Wings Having Aspect Ratios of 4, Spanwise Variations in Thickness Ratio, and Variations in Plan-Form Taper - Transonic Bump Technique. NACA RM A53L17, 1954.

5. Nelson, Warren H., and Krumm, Walter J.: The Transonic Characteristics of 38 Cambered Rectangular Wings of Varying Aspect Ratio and Thickness as Determined by the Transonic Bump Technique. NACA RM A52D11, 1952.

6. Axelson, John A., and Taylor, Robert A.: Preliminary Investigation of the Transonic Characteristics of an NACA Submerged Inlet. NACA RM A50C13, 1950.

7. Emerson, Horace F., and Gale, Bernard: Transonic Aerodynamic Characteristics of Three Thin Triangular Wings and a Trapezoidal Wing, All of Low Aspect Ratio. NACA RM A52D21, 1952.

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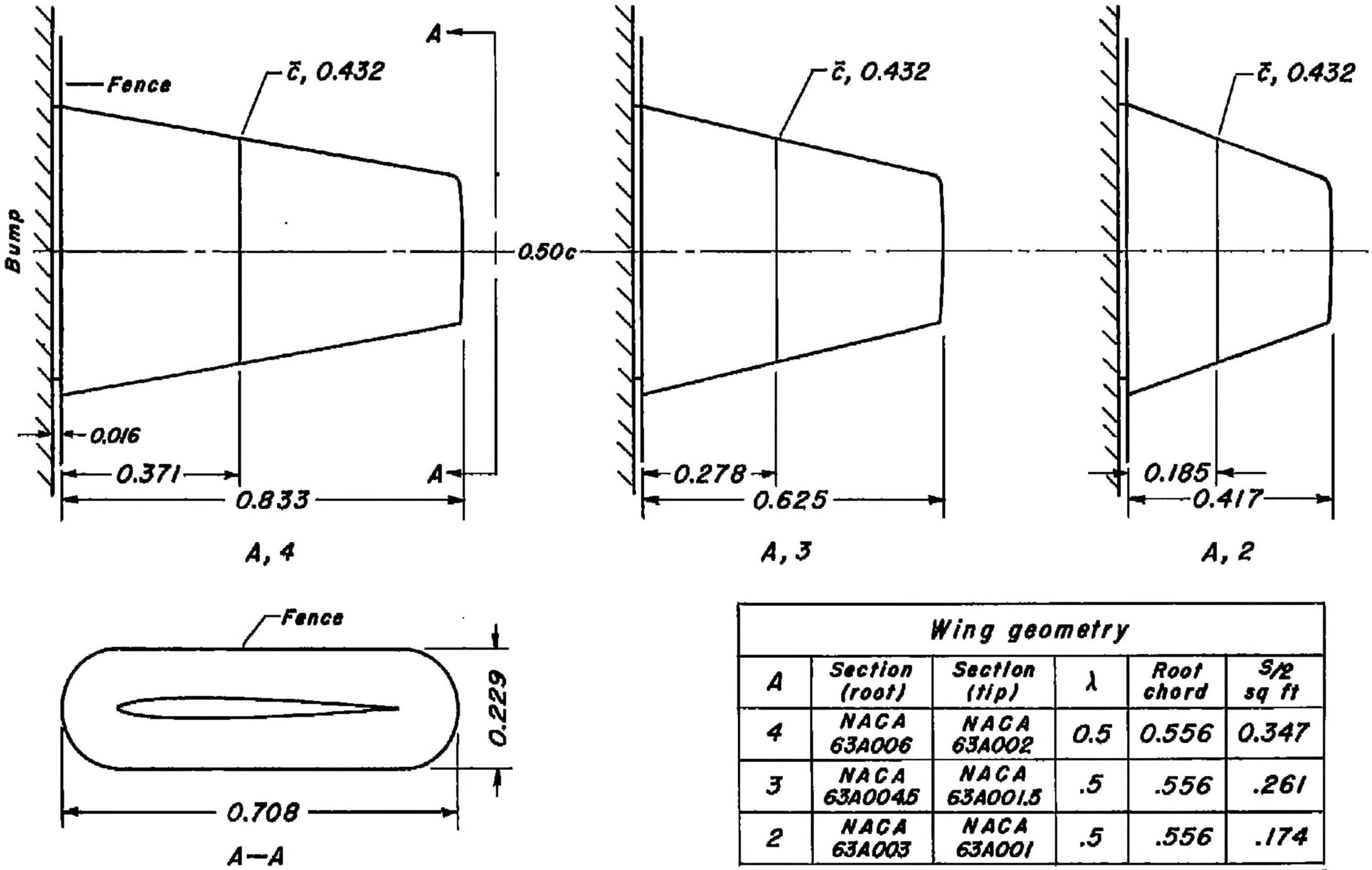

Wing geometry					
A	Section (root)	Section (tip)	λ	Root chord	S/2 sq ft
4	NACA 63A006	NACA 63A002	0.5	0.556	0.347
3	NACA 63A004.5	NACA 63A001.5	.5	.556	.261
2	NACA 63A003	NACA 63A001	.5	.556	.174

Note: All dimensions in feet unless otherwise specified.

Figure 1.- Dimensions and plan forms of the three wings.

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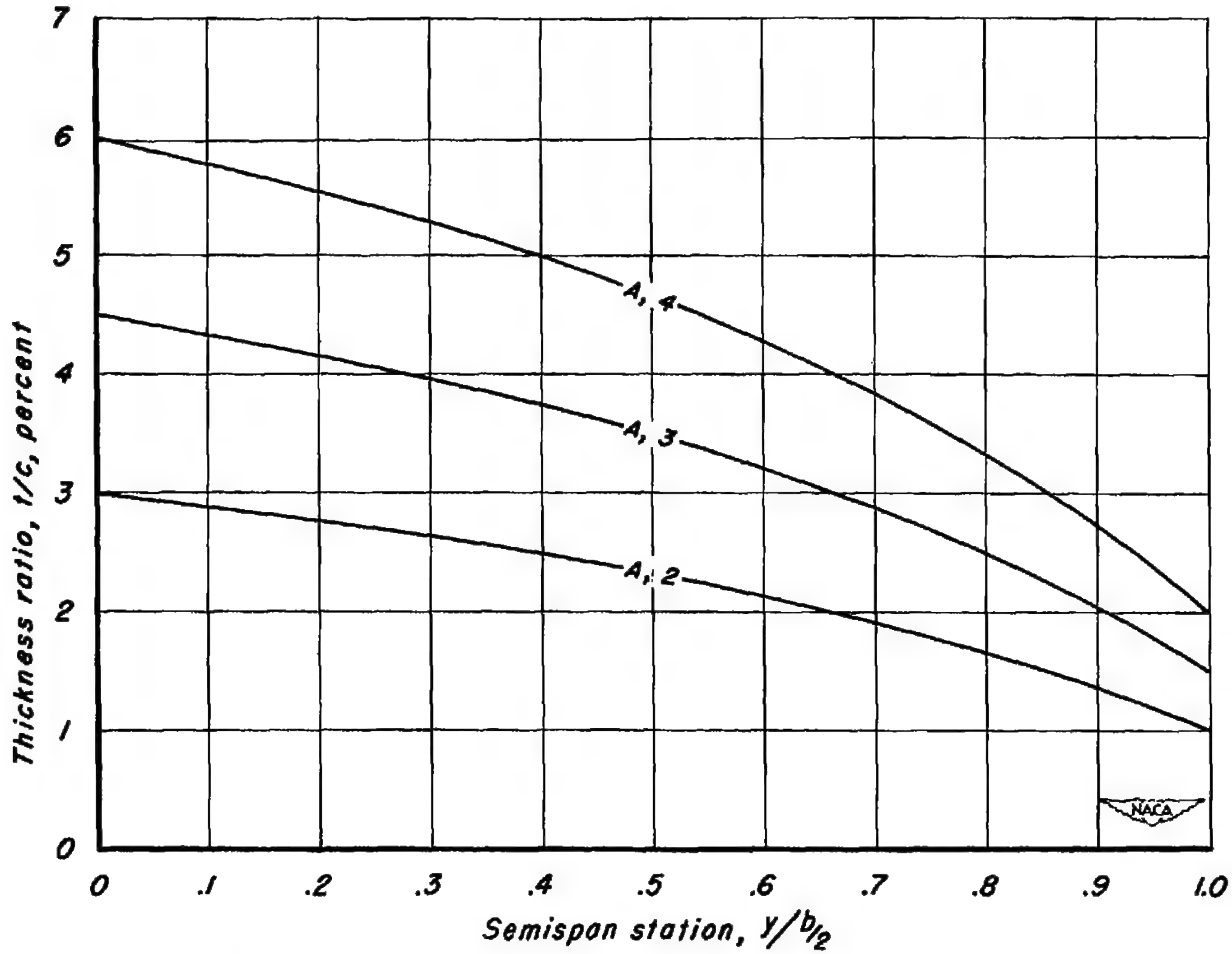

Figure 2.- The variation of thickness ratio with semispan station for the three wings.

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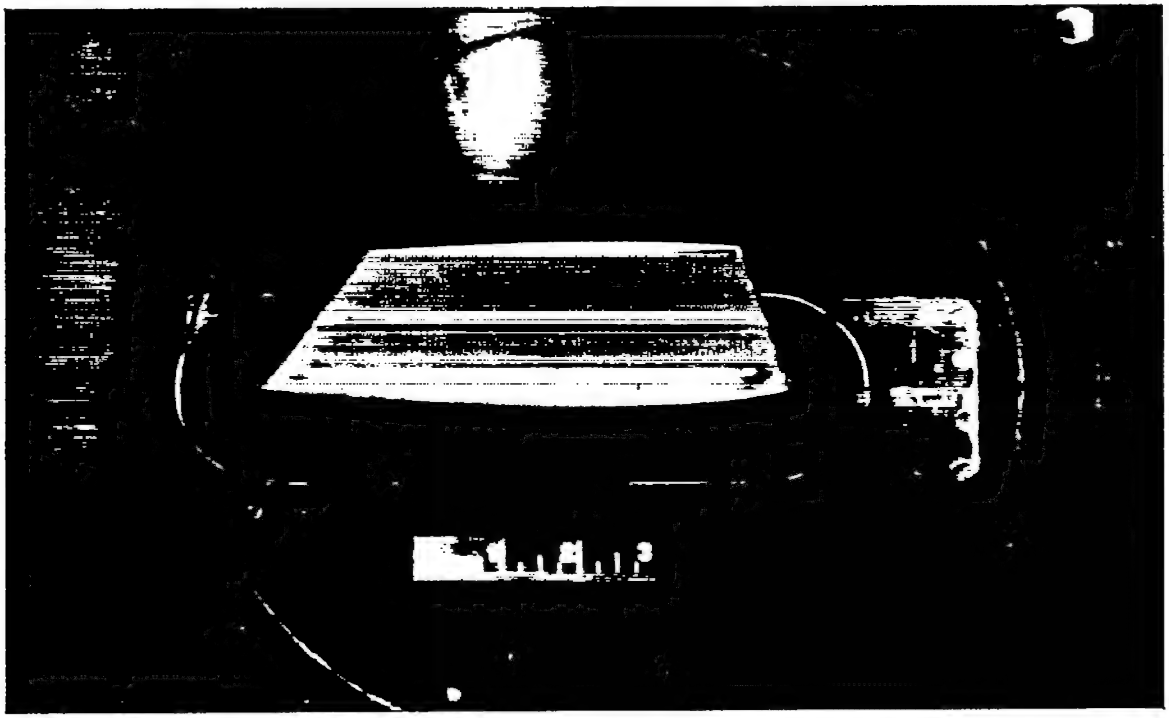

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Figure 3.- The wing having an aspect ratio of 4 mounted on the transonic bump in the Ames 16-foot high-speed wind tunnel.

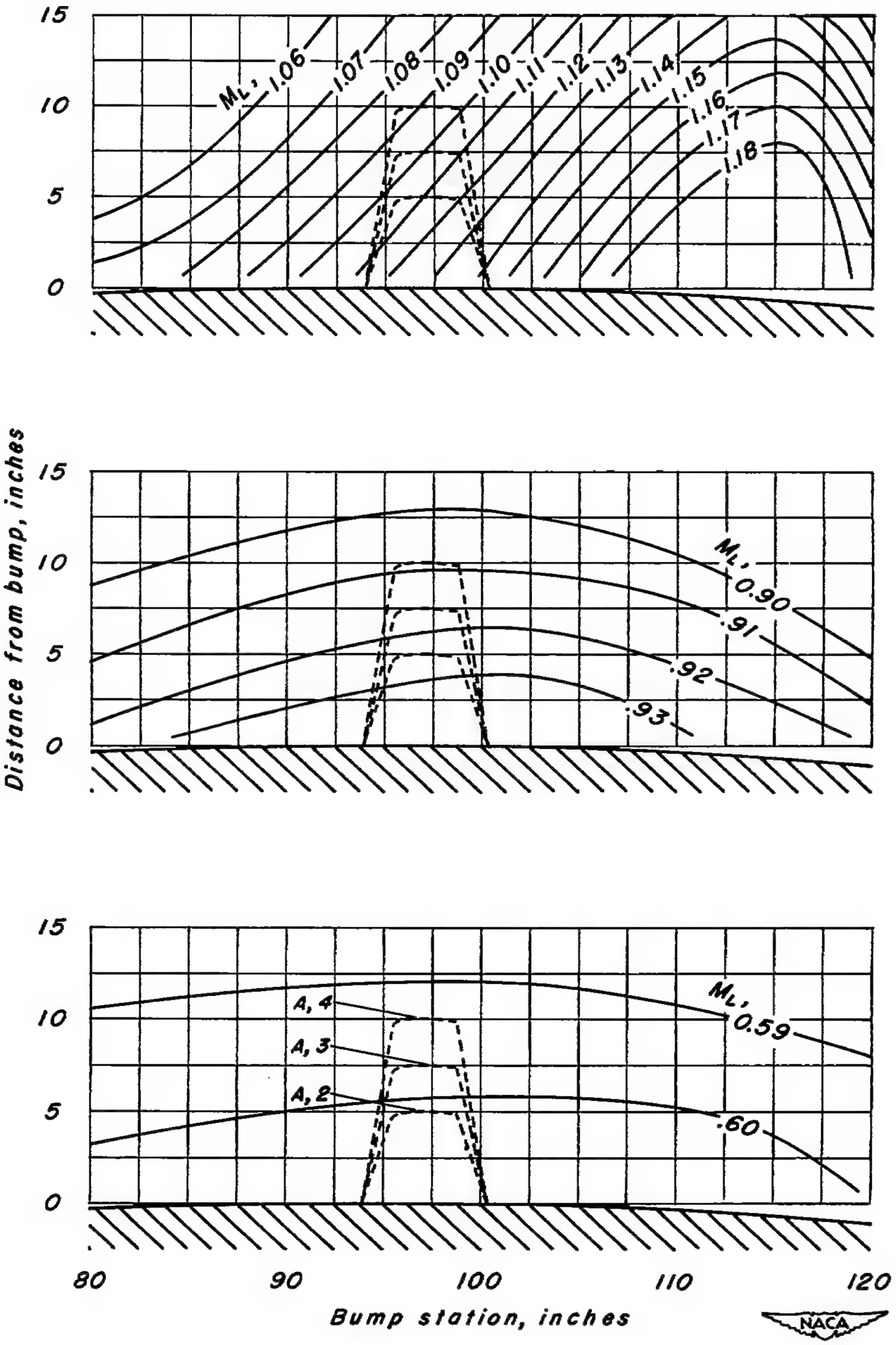

Figure 4.- Typical Mach number contours over the bump.

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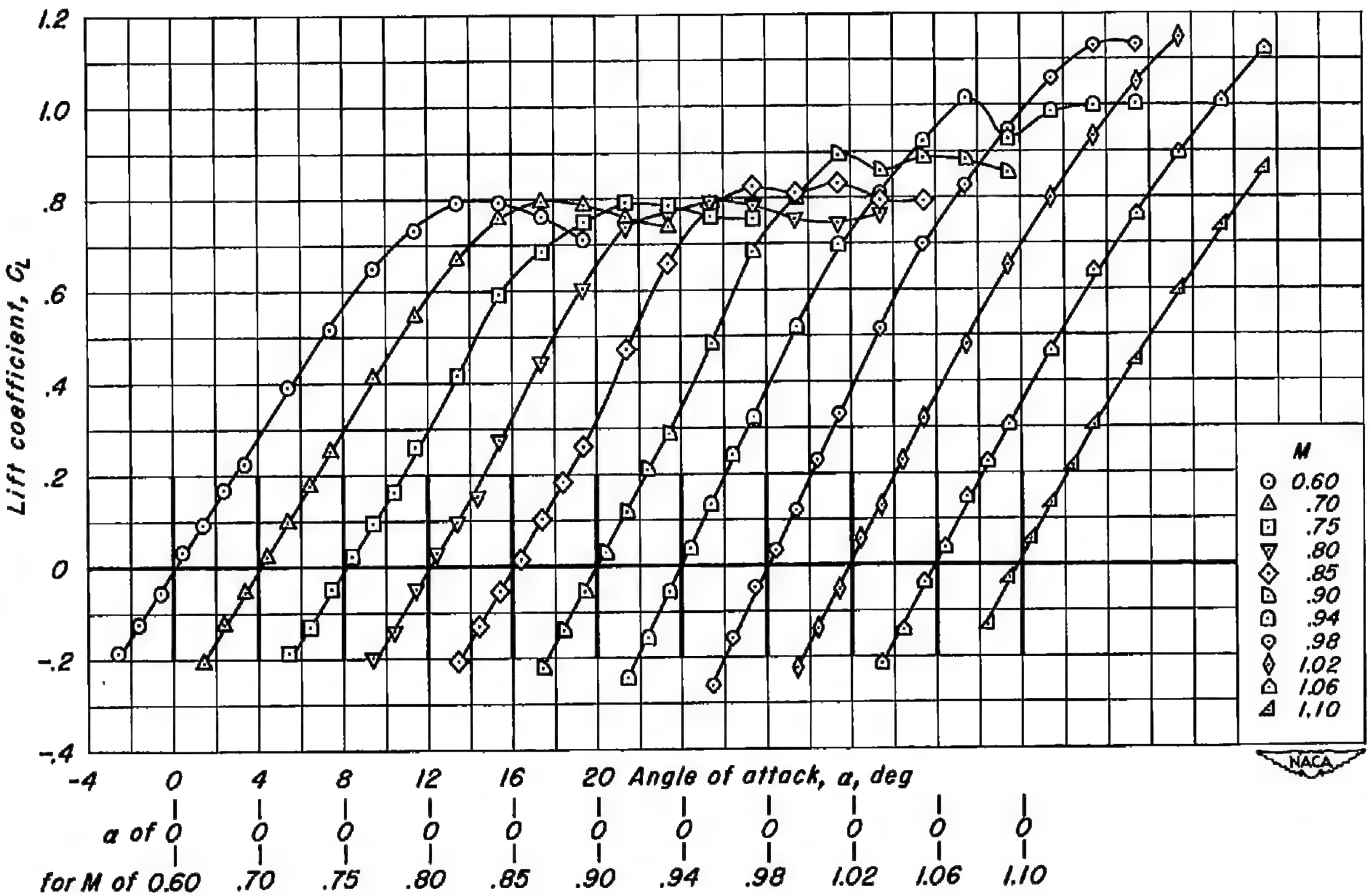

(a) Lift characteristics.

Figure 5.- The aerodynamic characteristics of the wing having an aspect ratio of 4.

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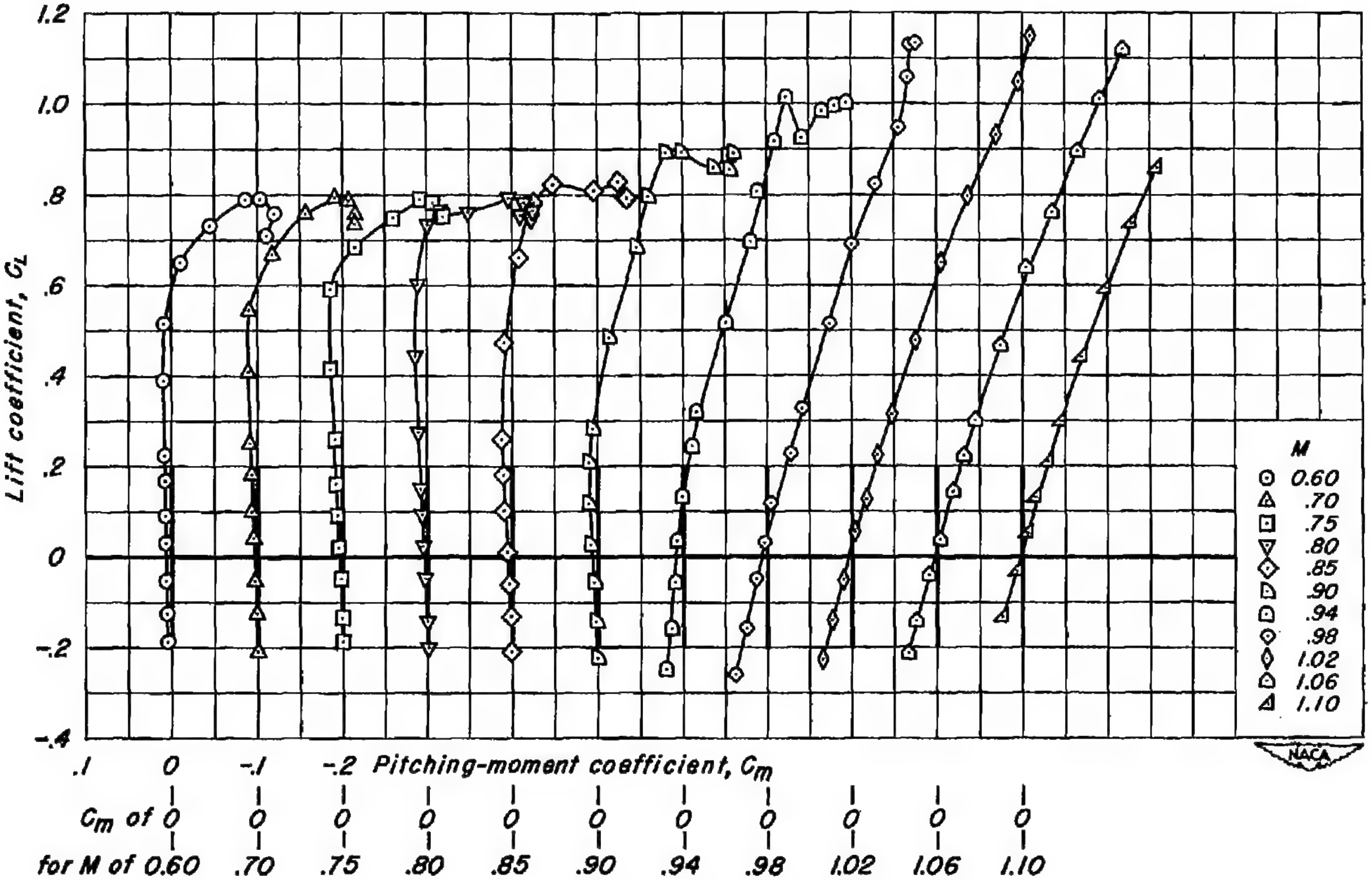

(b) Pitching-moment characteristics.
Figure 5.- Continued.

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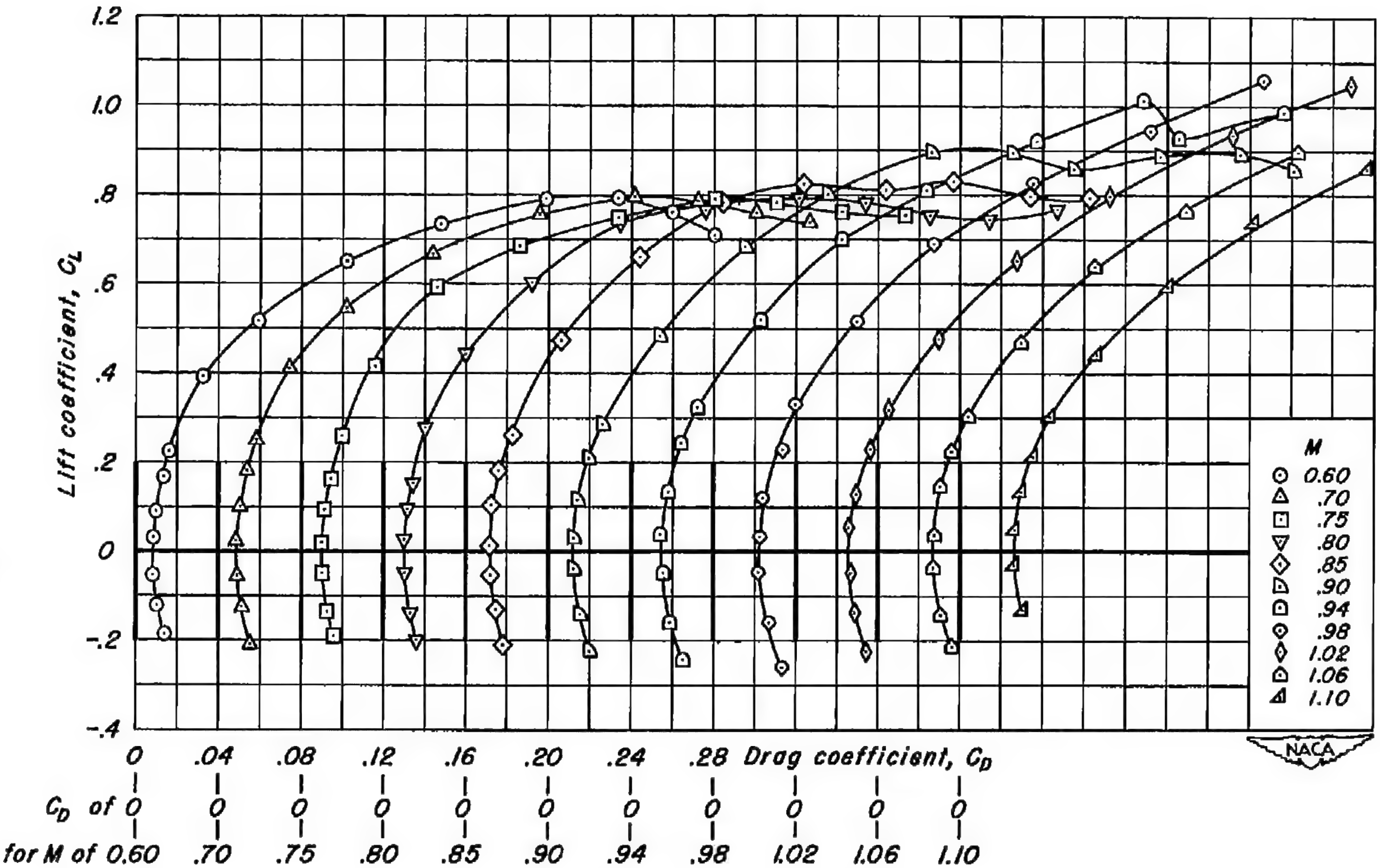
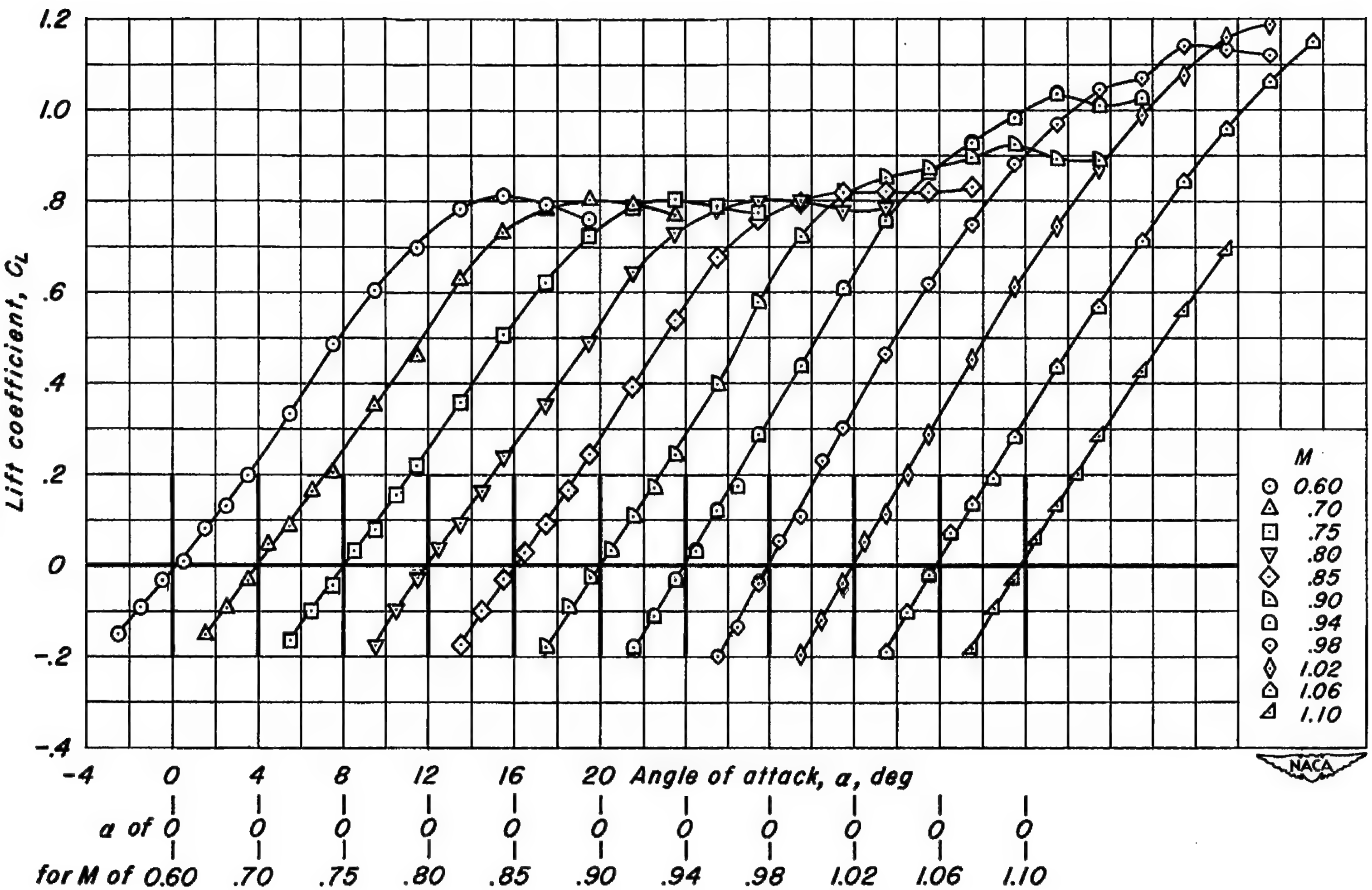
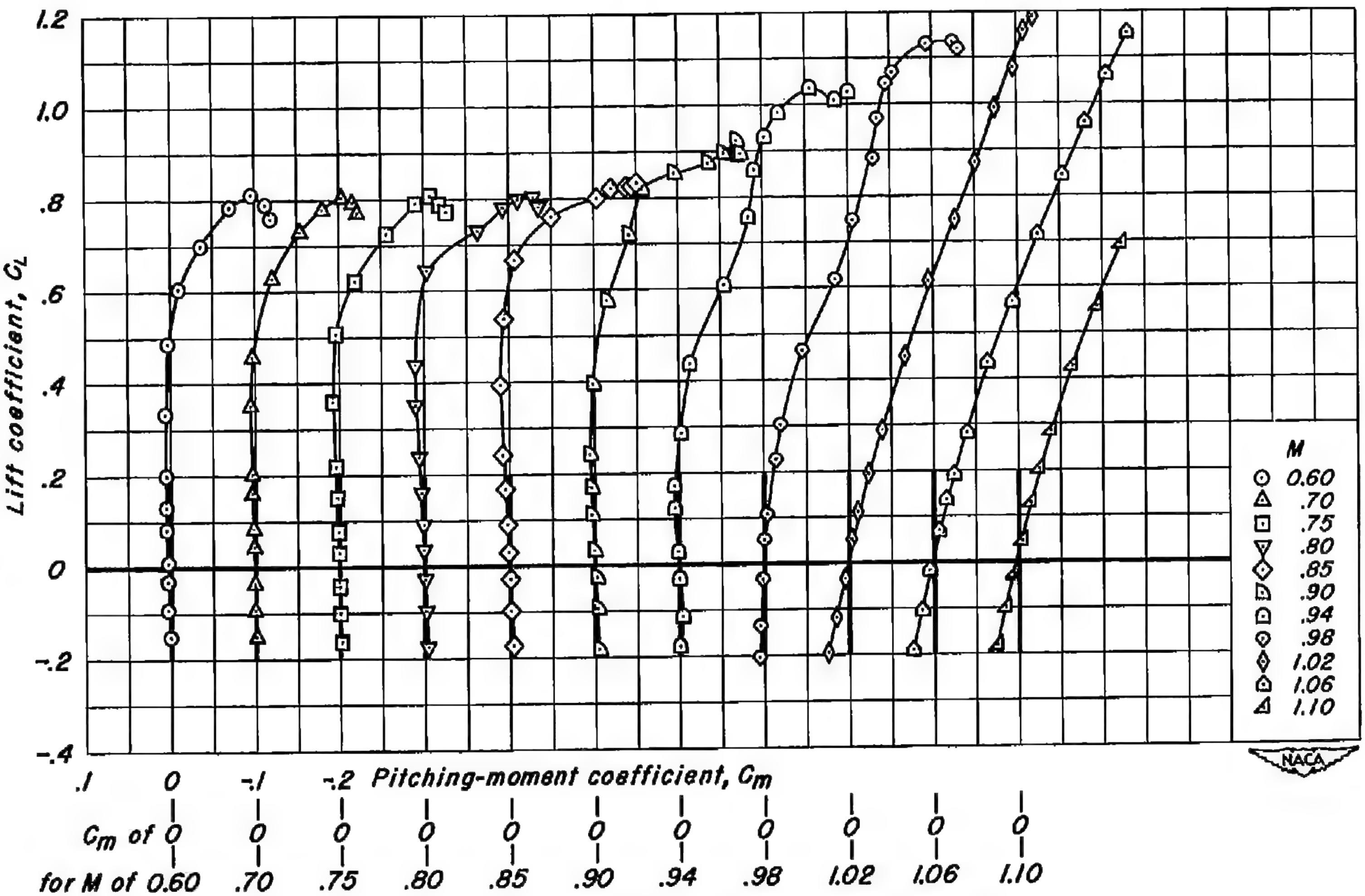


(c) Drag characteristics.
Figure 5.- Concluded.

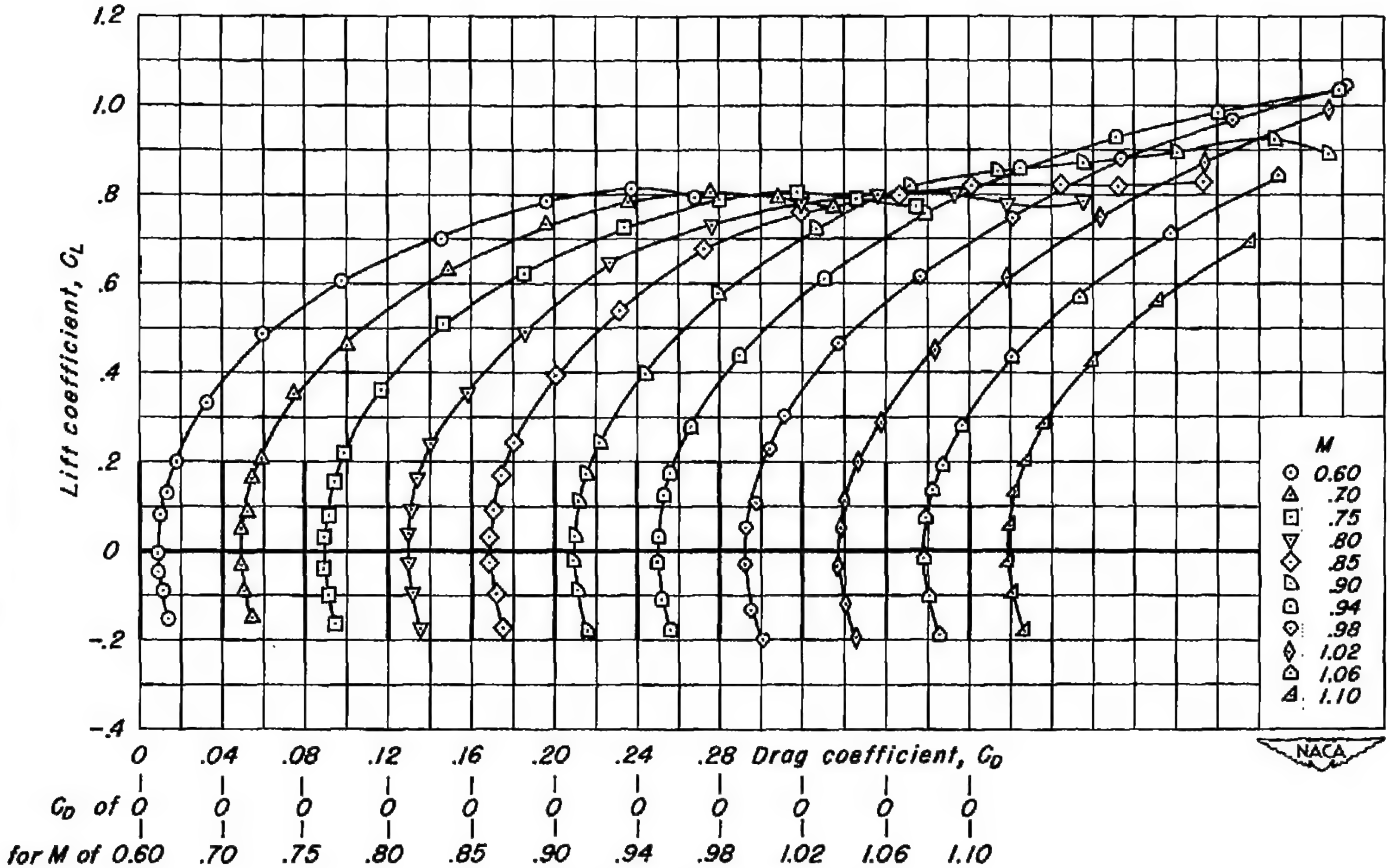


(a) Lift characteristics.

Figure 6.- The aerodynamic characteristics of the wing having an aspect ratio of 3.

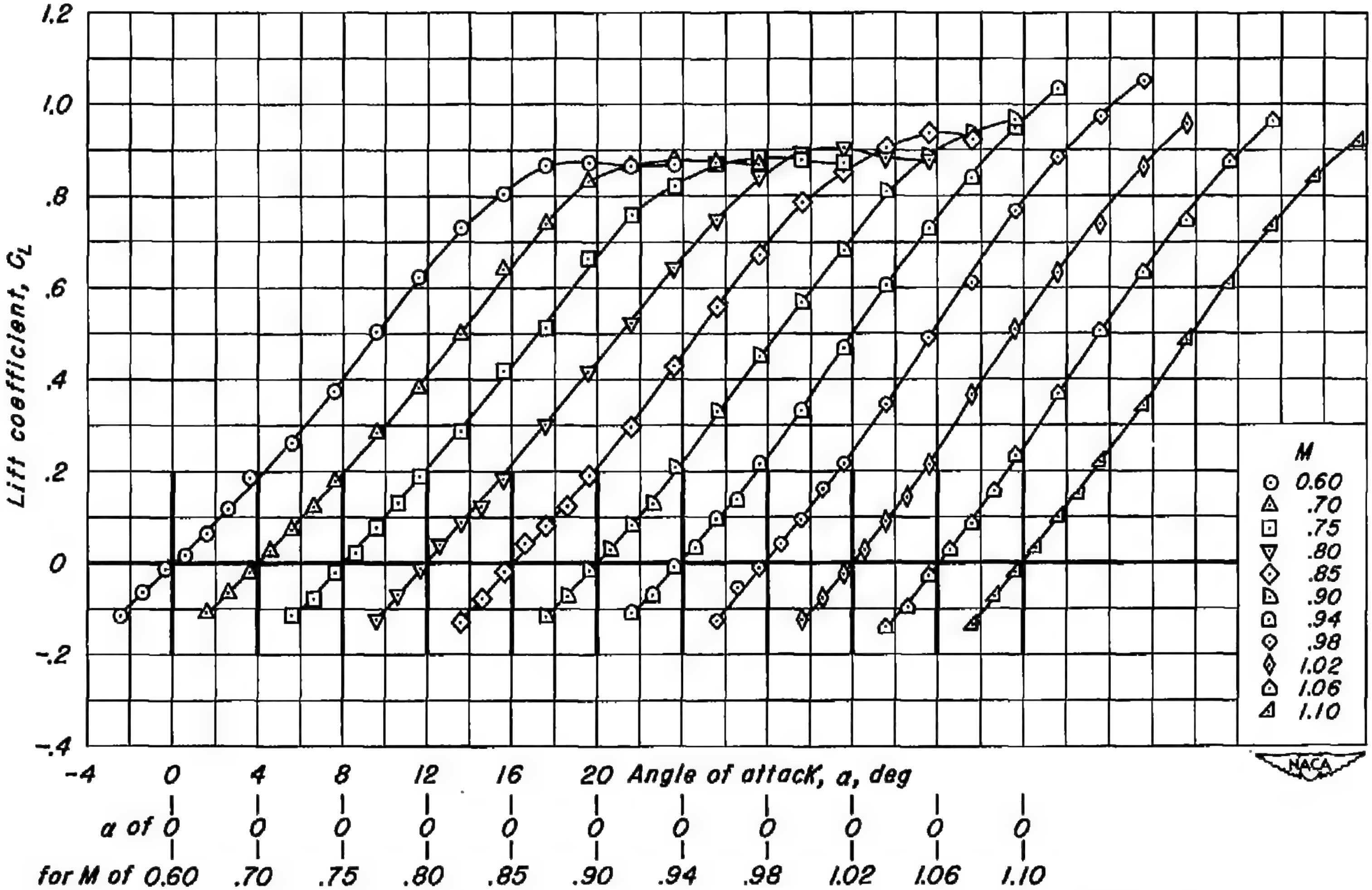


(b) Pitching-moment characteristics.
Figure 6.- Continued.



(c) Drag characteristics.

Figure 6.- Concluded.



(a) Lift characteristics.

Figure 7.- The aerodynamic characteristics of the wing having an aspect ratio of 2.

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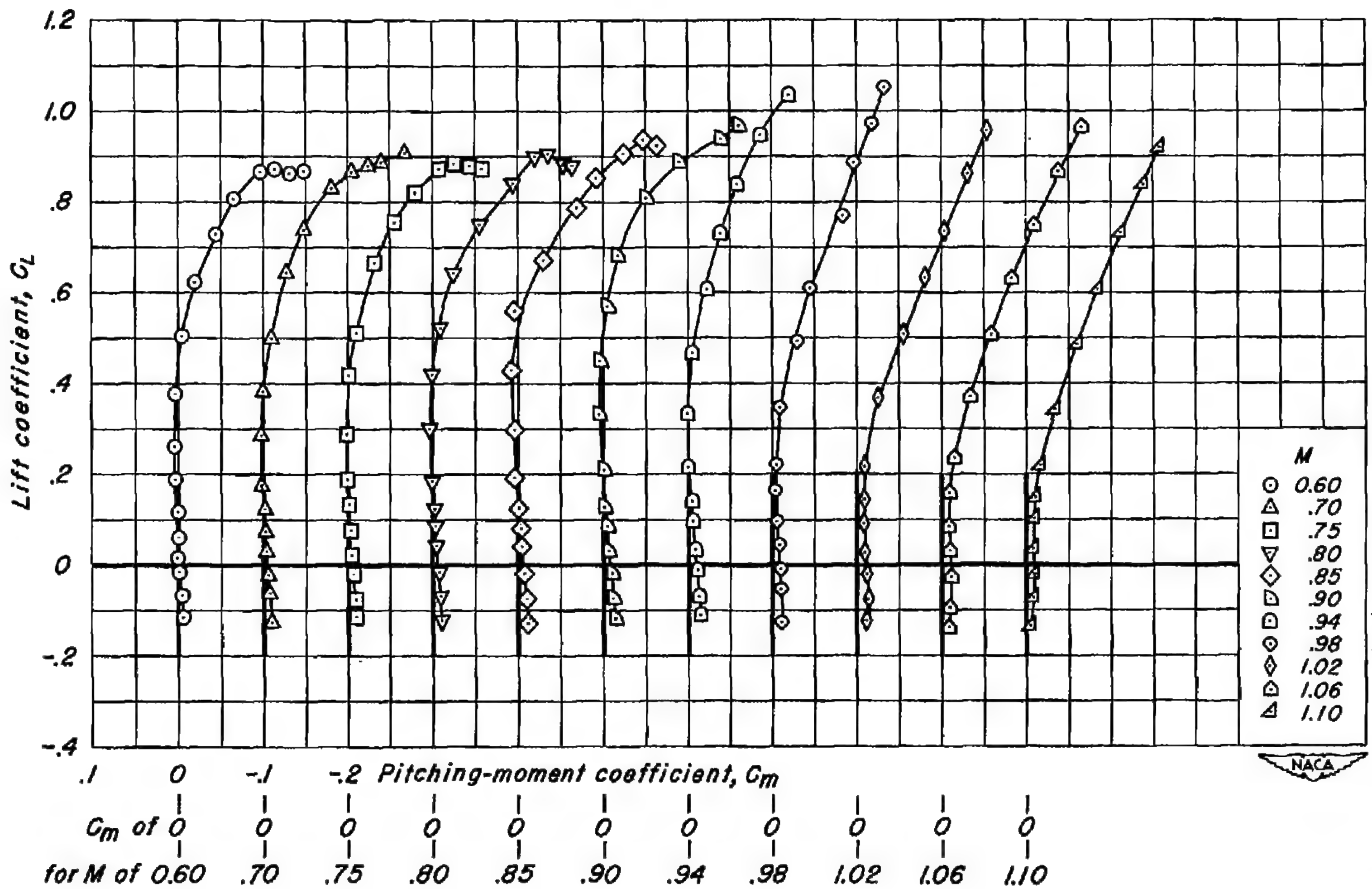

(b) Pitching-moment characteristics.
Figure 7.- Continued.

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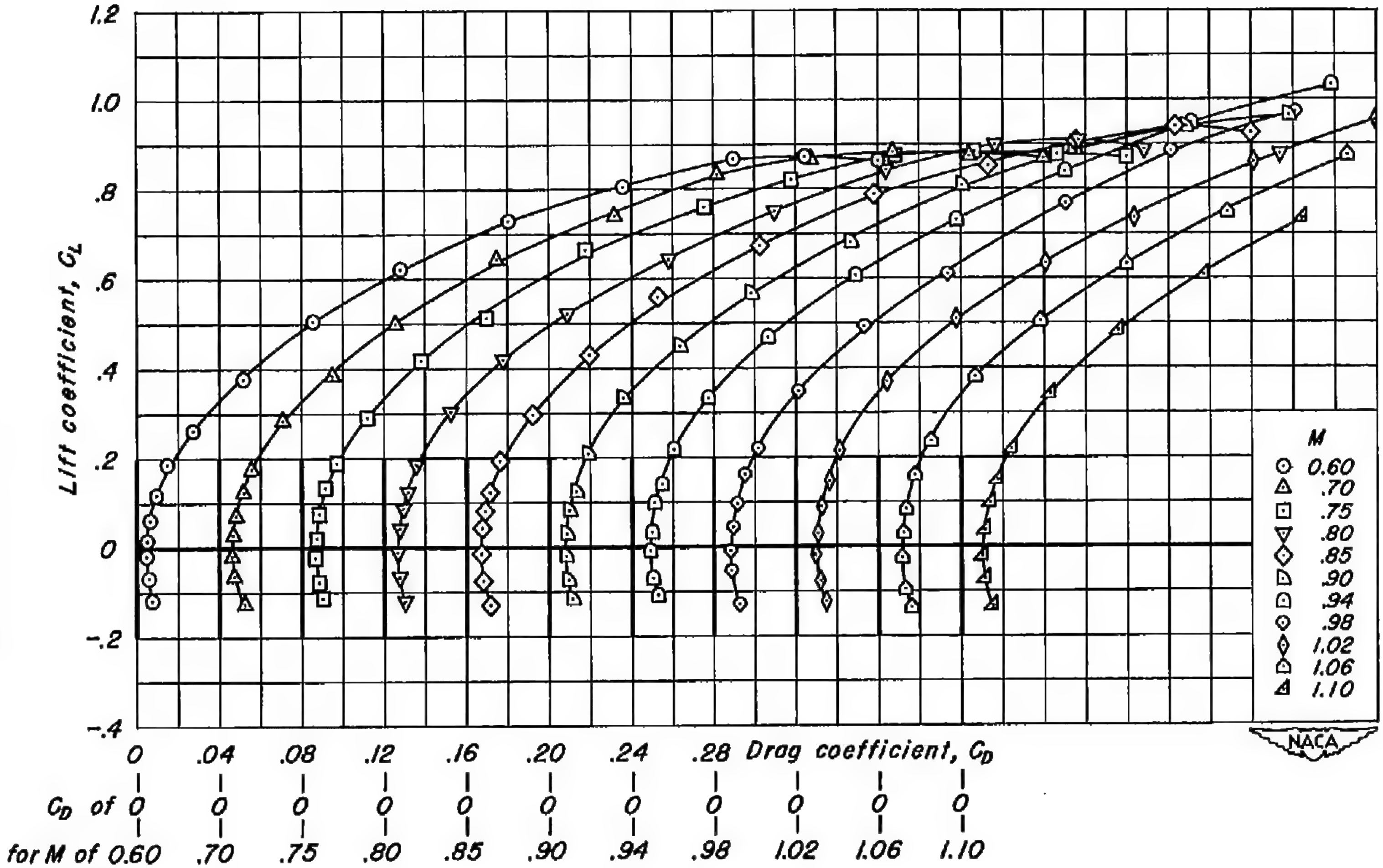

(c) Drag characteristics.

Figure 7.- Concluded.

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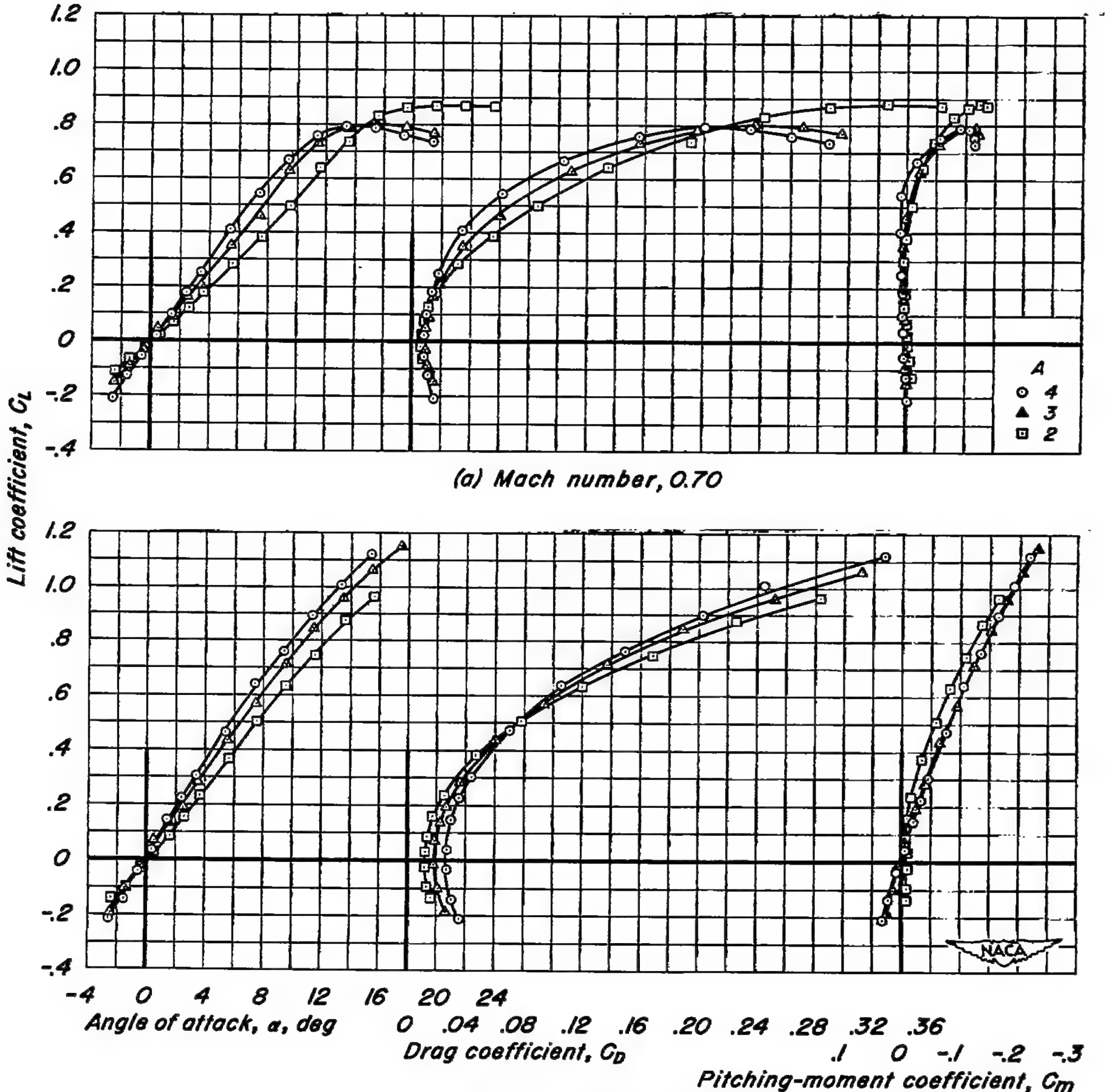


(b) Mach number, 1.06

Figure 8.- The lift, drag, and pitching-moment characteristics of the wings.

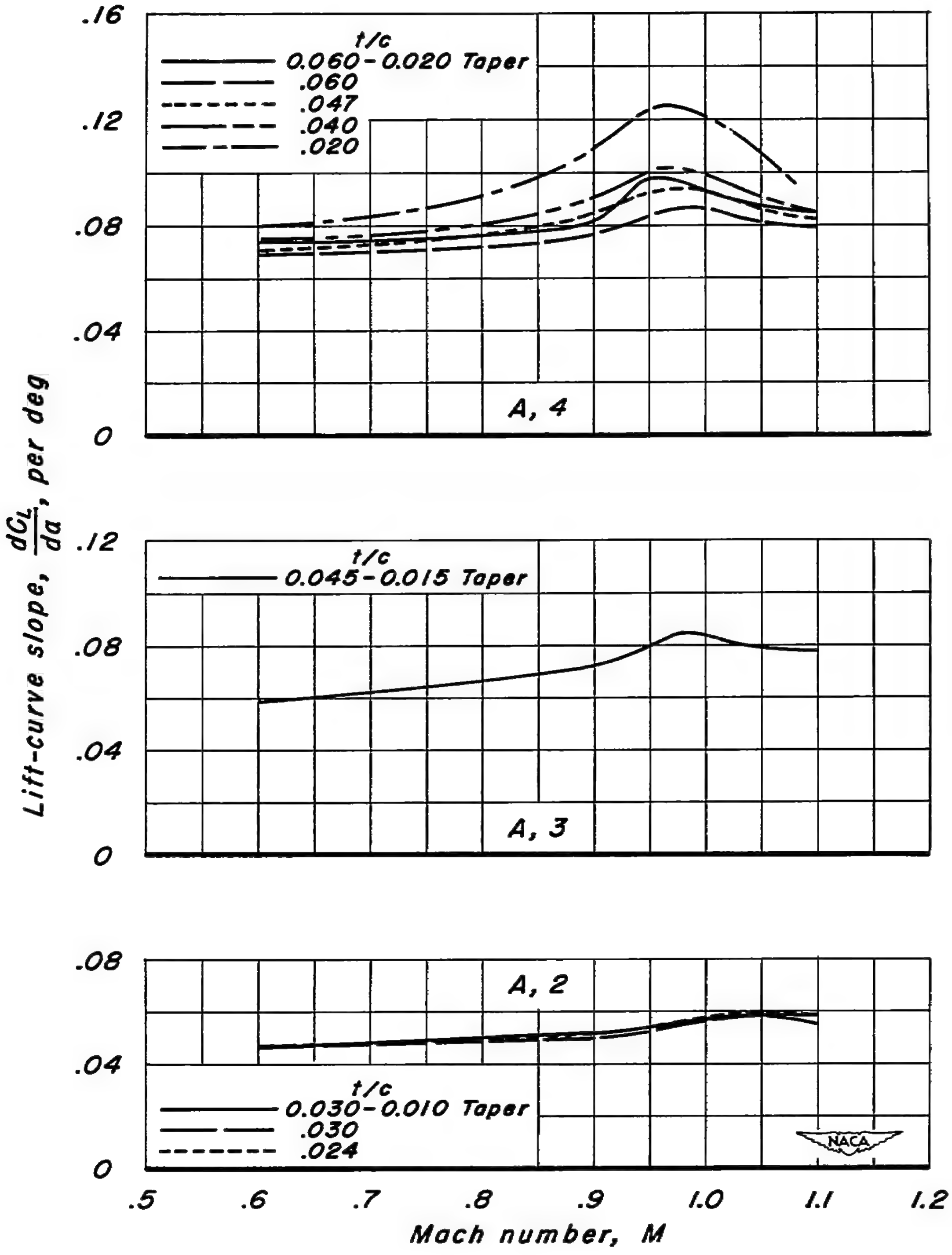


Figure 9.- The variation of lift-curve slope with Mach number. $C_L = 0$.

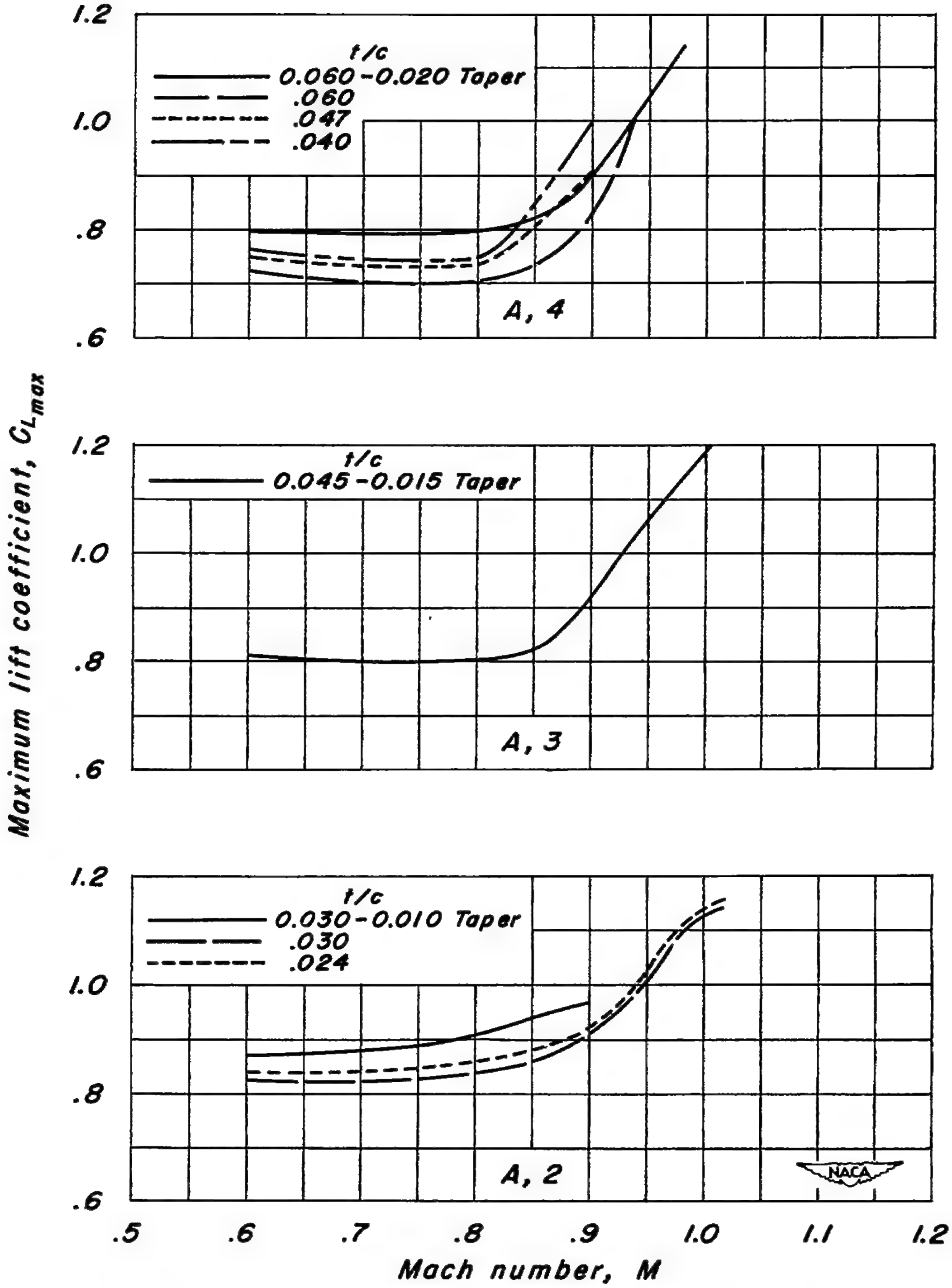


Figure 10.- The variation of maximum lift coefficient with Mach number.

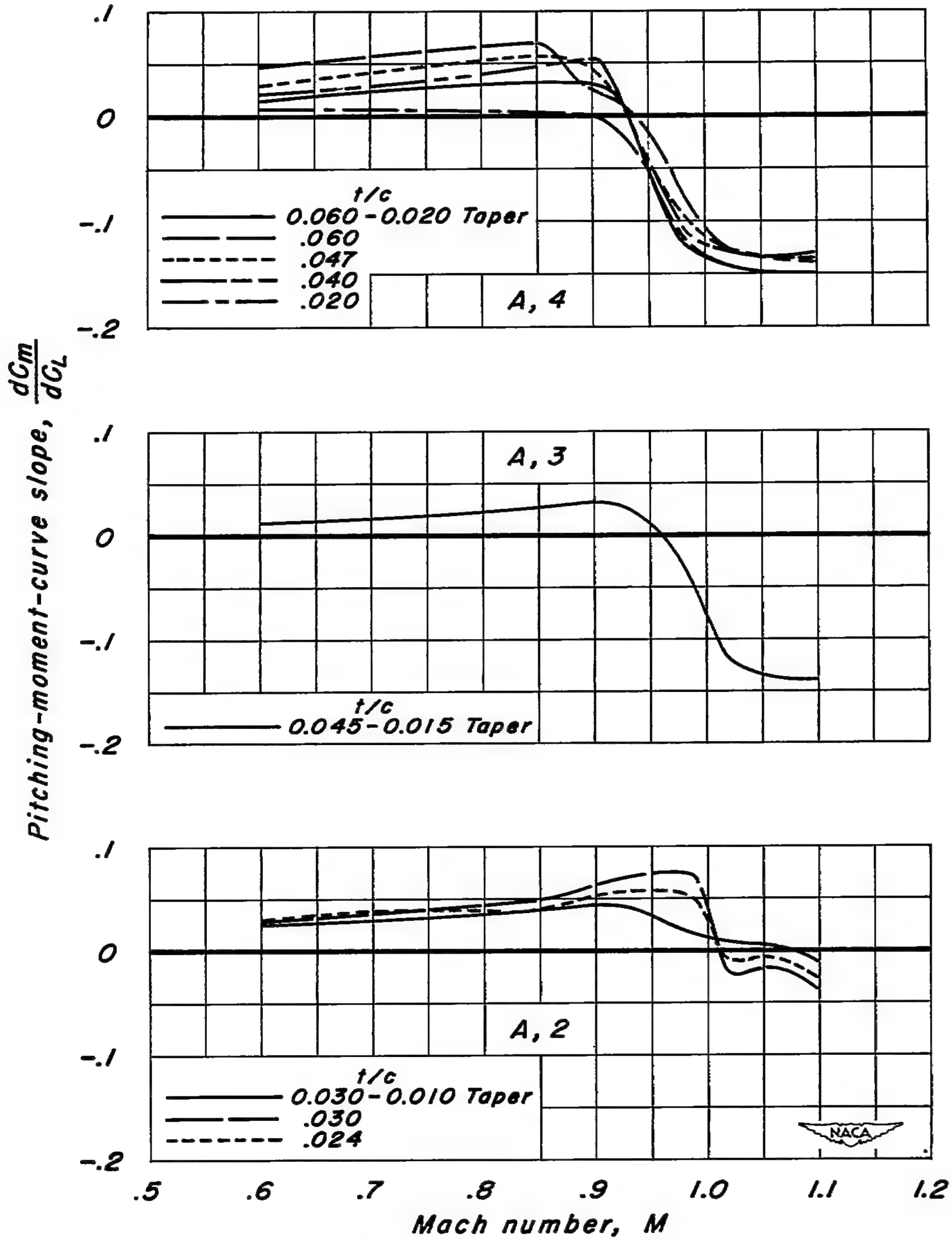
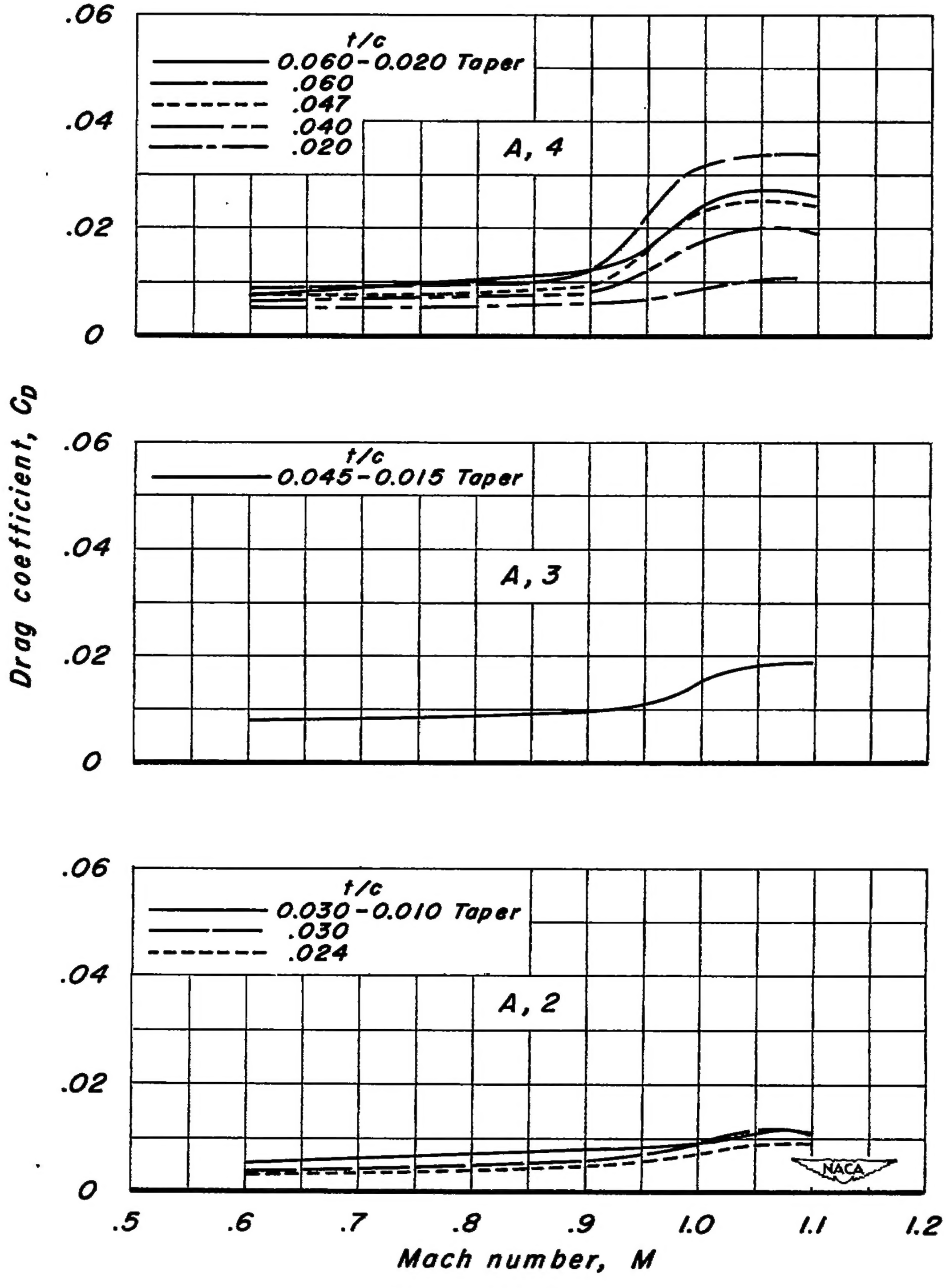
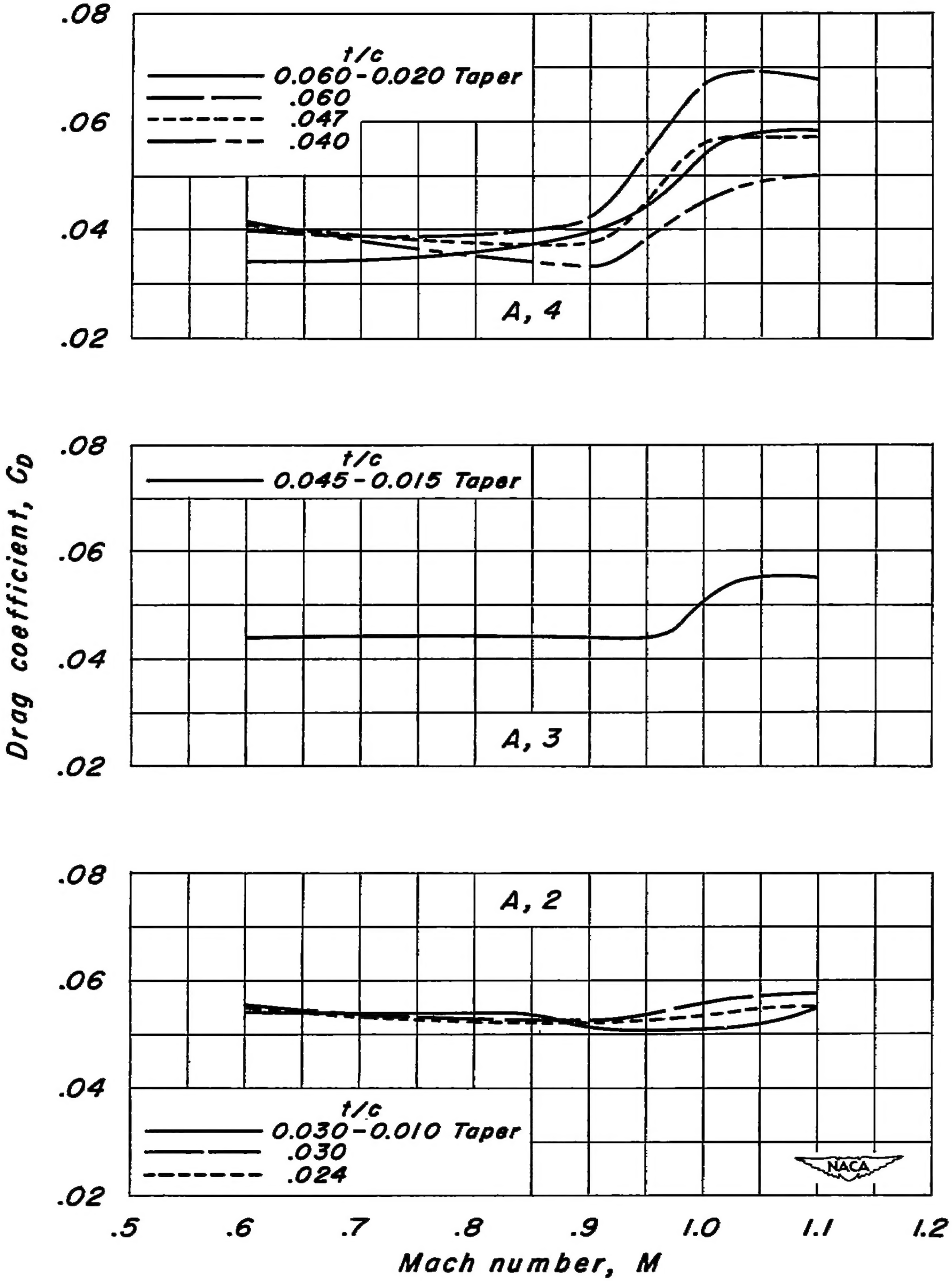


Figure 11.- The variation of pitching-moment-curve slope with Mach number. $C_L = 0$.



(a) Lift coefficient, 0.
Figure 12.- The variation of drag coefficient with Mach number.



(b) Lift coefficient, 0.4.
Figure 12.- Concluded.

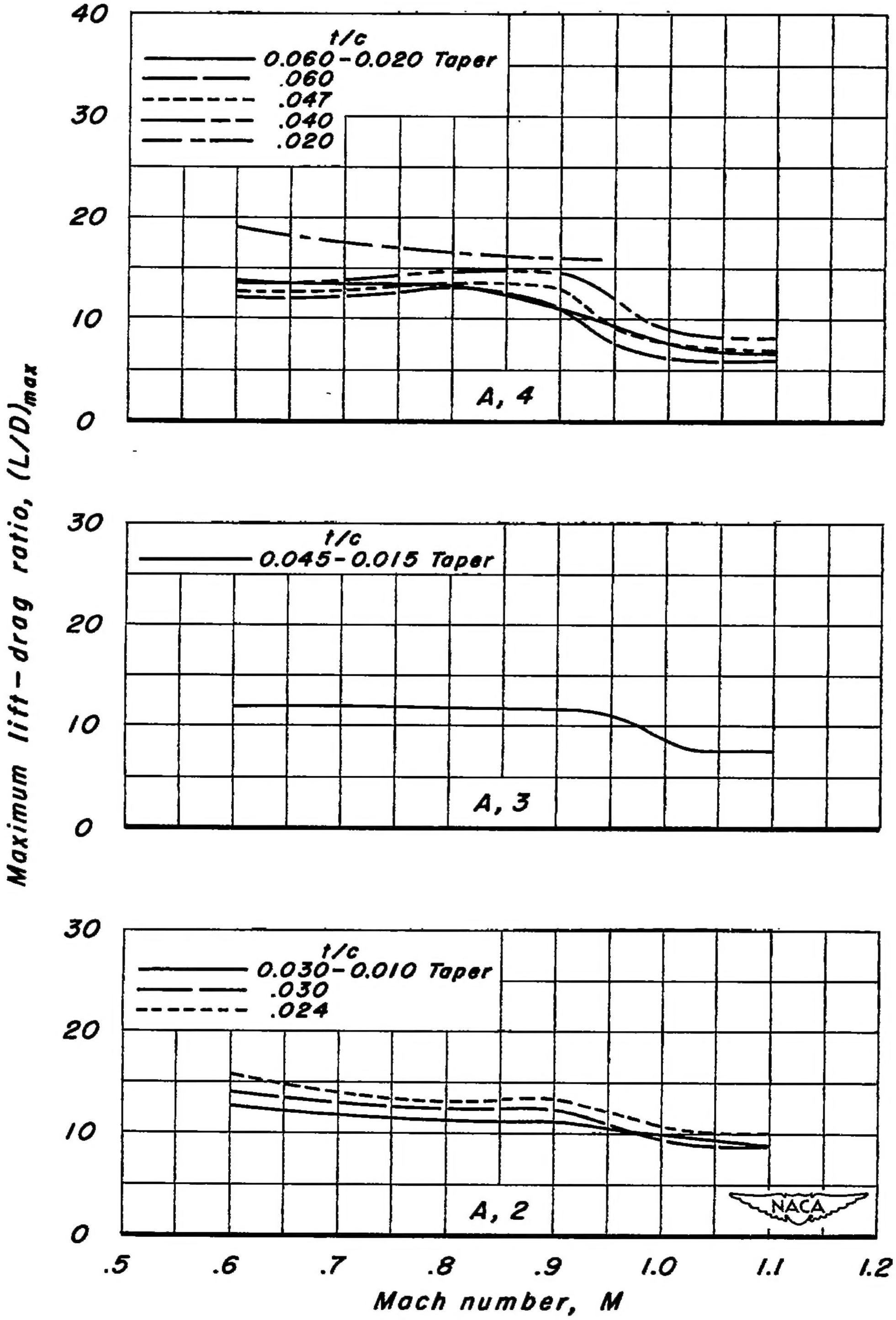


Figure 13.- The variation of maximum lift-drag ratio with Mach number.

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